CLIVAR/CO_2 Repeat Hydrography Program: Initial Results in the North Atlantic Ocean

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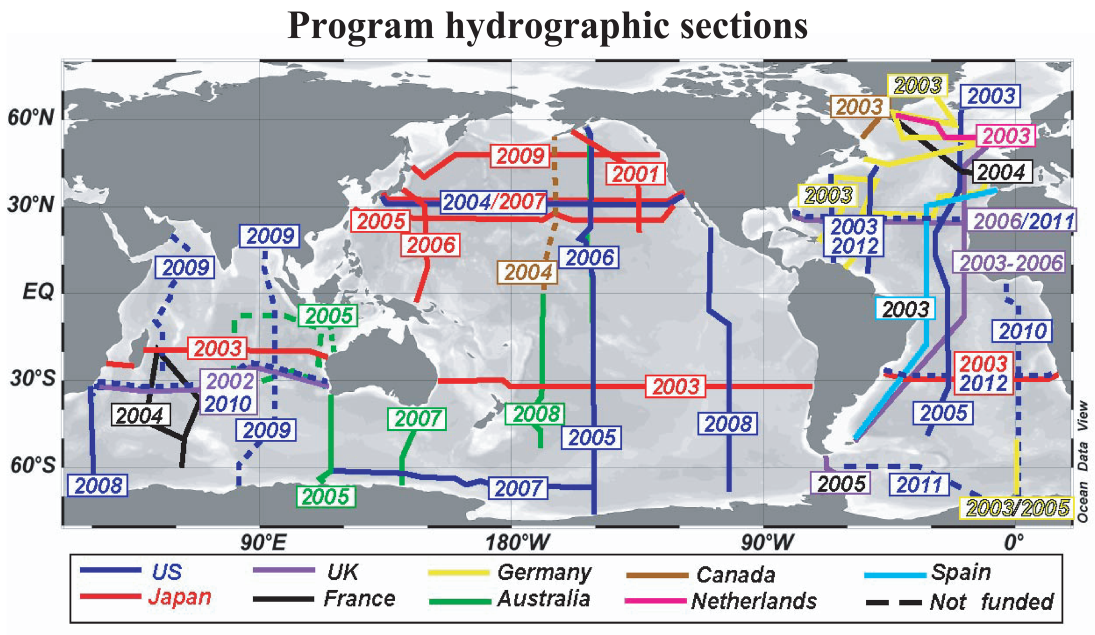
Objectives:

- **Data for Model Calibration and Validation**
- **Carbon System Studies**
- **Heat and Freshwater Storage and Flux**
- **Deep and Shallow Water Mass and Ventilation**
- **Calibration of Autonomous Sensors**

Approach:

The Repeat Hydrography CO_2/tracer Program is being implemented to maintain decadal time-scale changes in ocean transports and inventories of climatically significant parameters. The sequence and timing for the sections takes into consideration the program objectives, providing global coverage, and anticipated resources. The sections have been selected so that there is roughly a decade between them and the WOCE/JGOFS global survey.

Global map of planned Repeat Hydrography CO_2/tracer Program hydrographic sections



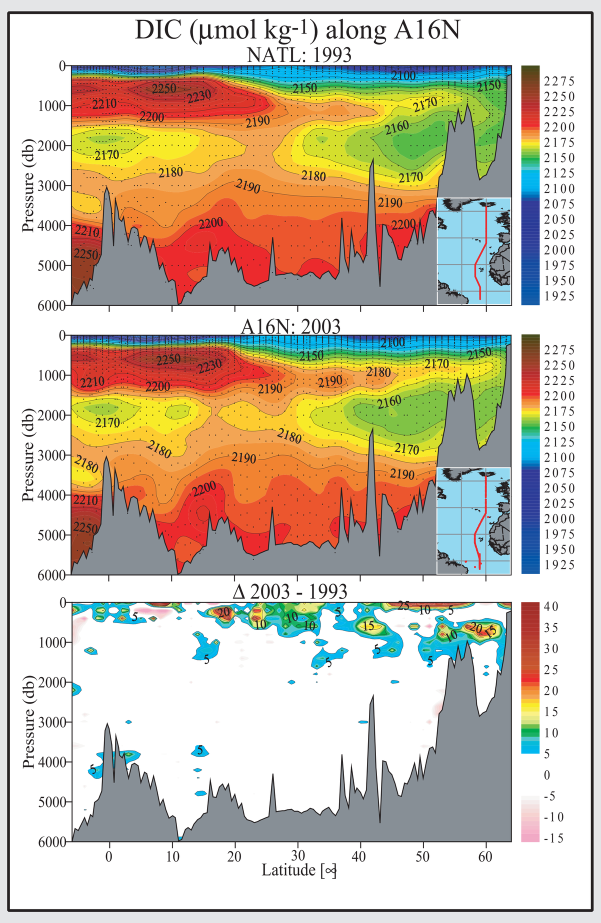
Achievements:

A16N:

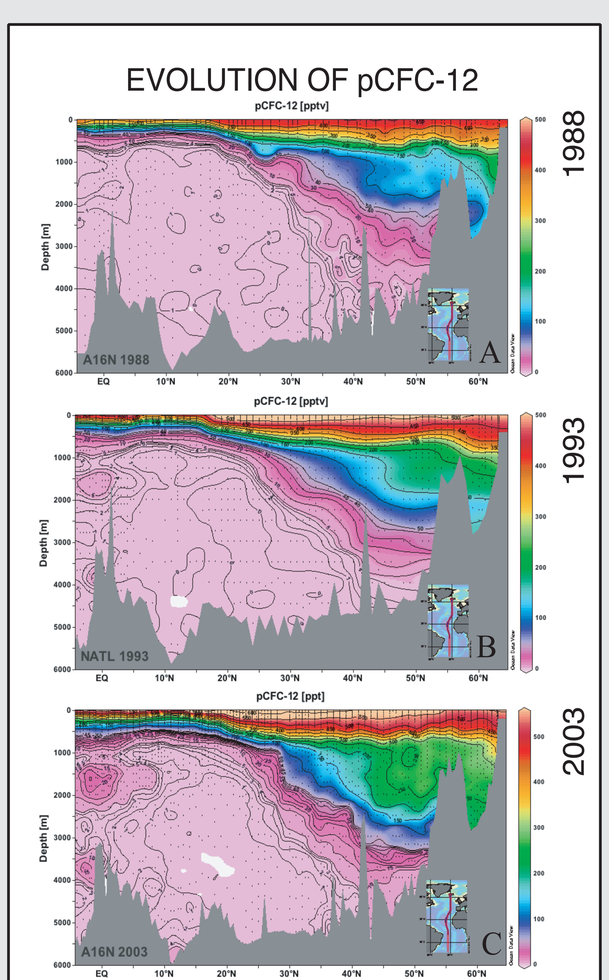
In the two-month period between June and August 2003, the first survey (Repeat Hydrography Section A16N) as part of the Repeat Hydrography CO_2/tracer Program was successfully completed in the North Atlantic on NOAA Ship *Ronald H. Brown*. The cruise ran from Iceland southward past the equator and repeated an oceanographic section occupied in 1988, and again in 1993, looking for possible changes in the physics, chemistry and biology of the ocean in this region. The sampling rosette/CTD system worked without failure for 150 deep ocean casts, providing ~ 5000 water samples for analysis.

The figure to the right shows the A16N DIC sections occupied in 1993 (top), 2003 (middle) and the 2003 - 1993 difference (bottom). The increases in DIC between 1993 and 2003 indicate that the upper and mid-thermocline waters in this region of the northern North Atlantic are rapidly accumulating anthropogenic CO_2 on decadal time scales. The significant DIC increase of about 5 – 22 µmol kg^{-1} at intermediate depths from about 100 – 800m north of ~ 20°N reflect, in part, the rapid uptake and transport of anthropogenic CO_2 in this water mass. Mode waters in the North Atlantic Ocean are formed each winter by cooling and convective mixing. A lack of strong wintertime mixing north of 20°N during the latter half of the decade of the 1990s (NAO positive phase) may have caused the anthropogenic CO_2 to be trapped in this layer and retained there for periods of several years.

DIC (µmol kg-1) along A16N



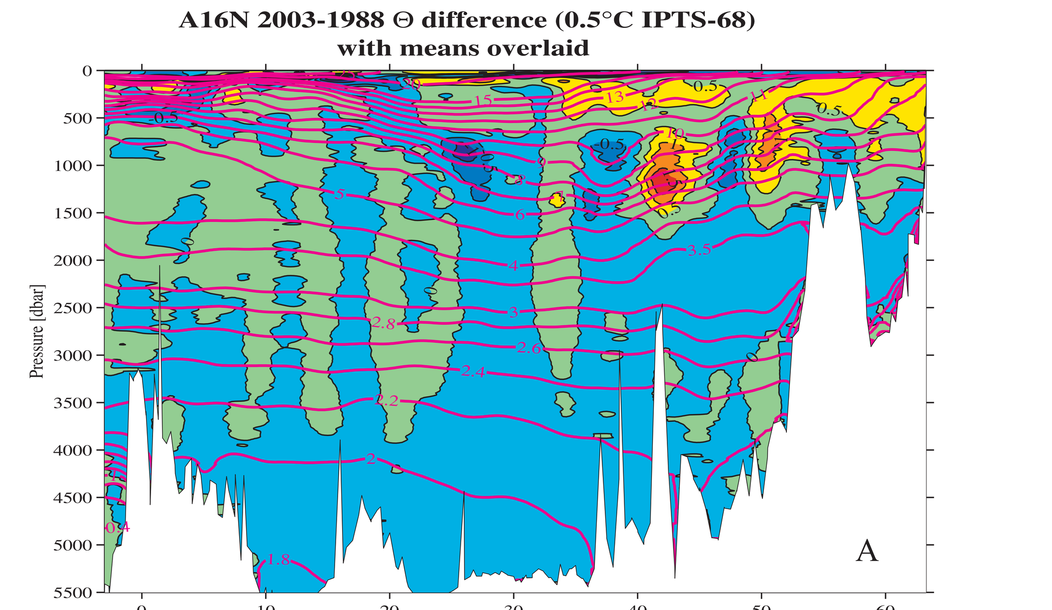
EVOLUTION OF pCFC-12



In the figure on the left, sections of CFC-12 from the three occupations of A16N in 1988 (A), 1993 (B), and 2003 (C) are shown. The increases in CFC-12 between 1988 and 2003 indicate that the upper and mid depth waters in this region of the northern North Atlantic are rapidly ventilated with atmospheric gases on decadal time scales. The strong CFC signal in waters from 1000 – 2000m depth north of ~ 40°N reflect the rapid ventilation and transport of Labrador Sea Water (LSW) into this region. A significant CFC signal is also present in abyssal waters at the northern end of the section, associated with the formation and outflow of North Atlantic Deep Waters, a key component of the global thermohaline circulation. Of particular interest is the development of a CFC-12 maximum near the equator at a depths of ~1000 – 2000m associated with upper North Atlantic Deep Water. This maximum demonstrates that ocean circulation processes are rapid enough to carry these species, absorbed in surface waters in the high latitude North Atlantic, to the tropics on decadal time scales.

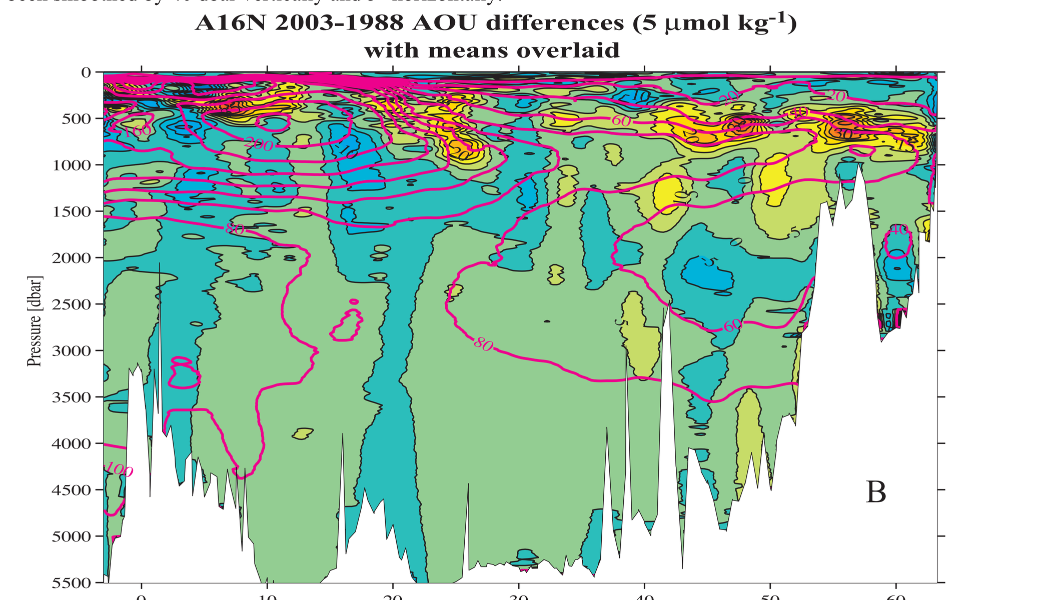
There are a few significant patterns in the differences of water properties both physical (e.g., temperature, Fig. A) and biogeochemical (e.g., apparent oxygen utilization, AOU, Fig. B) between the 2003 and 1988 reoccupations of A16N, a meridional section in the eastern basins of the North Atlantic.

A16N 2003-1988 Θ difference (0.5°C IPTS-68) with means overlaid



Potential temperature difference between the 2003 and 1988 occupations of A16N (filled colors at 0.5°C intervals with red indicating warming and blue cooling). Magenta contours (at irregular intervals) are the mean potential temperatures. Data have been smoothed by 40 dbar vertically and 5° horizontally.

A16N 2003-1988 AOU differences (5 µmol kg^{-1}) with means overlaid



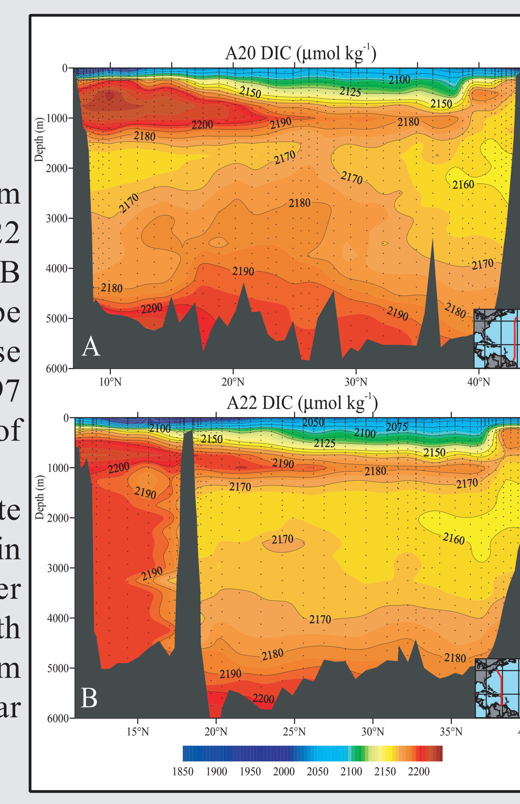
Apparent oxygen utilization (AOU) difference between the 2003 and 1988 occupations of A16N (filled colors at 5 µmol kg^{-1} intervals with red indicating higher AOU and blue lower AOU. Magenta contours (at 20 µmol kg^{-1} intervals) are the mean AOUs. Smoothing follows Fig. A.

1. Warming of ~ 0.5°C is evident between Iceland and 32°N from 100 and 700 dbar (Fig A). This warming is found within local mode waters (indicated by the widely spaced isotherms in the vertical starting near 7°C off Iceland and ending near 14°C by 32°N). The pattern suggests that in the ventilation time-period (roughly 5 years) prior to 2003 conditions were warmer, and these waters were less vigorously ventilated, than in the 5 years prior to 1988. Over the same latitude range, but between 300 and 1000 dbar, the AOU has risen between the 2003 and 1988 occupations (Fig. B). This increase in AOU within the oxycline is again consistent with less vigorous ventilation in the mode waters in the years prior to 2003 than in those prior to 1988.
2. The oscillating temperature (Fig. A) and AOU (Fig. B) differences between 20°N and 55°N from 600 – 1600 dbar are found within the influence of the Mediterranean outflow water, and likely represent mesoscale eddy variability.
3. The colder (Fig. A), lower AOU (Fig. B) and fresher (not shown) water between 40° N and Iceland from 1600 – 2600 dbar (near 3 – 3.5°C) reveals variability in the LSW penetrating to the eastern basins of the North Atlantic. LSW was more vigorously ventilated in the years leading up to 2003 than in the years prior to 1988, consistent with the water property patterns observed.

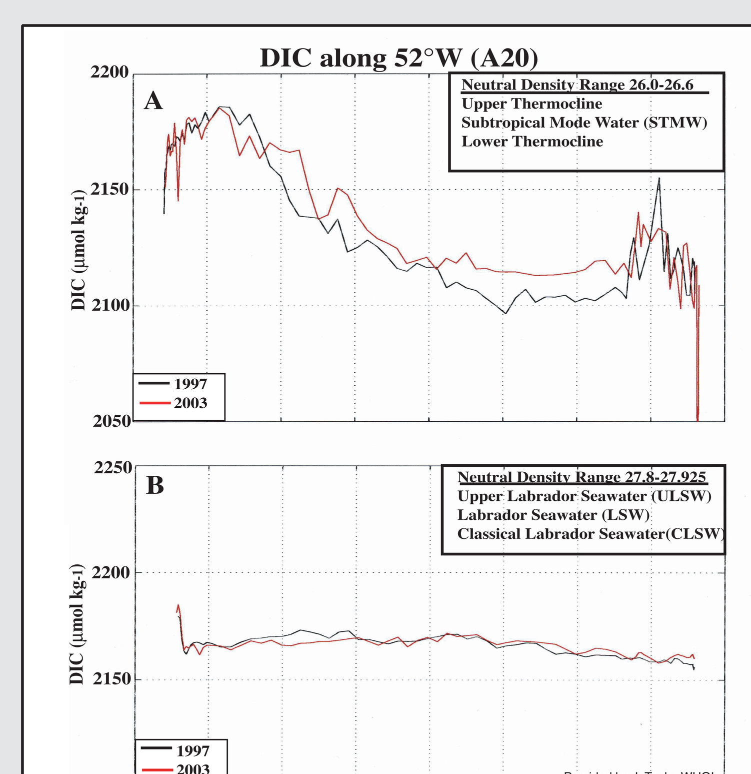
A20/22:

The DIC results from the A20 and A22 cruises (Figs. A and B respectively) can be compared to cruise results from the 1997 WOCE occupations of these sections.

The results indicate significant increases in the shallow water masses over the depth range of 100 – 600m during the 6 year period.



DIC along 52°W (A20)



Along the 26.0 – 26.6 neutral density field on 52°W (A20), DIC increases of 2 – 20 µmol kg-1 were observed over the six year period between the two cruises (Fig. A) In contrast, the DIC changes at a deeper density horizon (27.80 – 27.93) showed very little change (Fig. B). These increases of DIC in the Subtropical Mode Water (STMW) may be the result of decadal changes in the local circulation, invasion of anthropogenic CO_2 into the interior North Atlantic, and/or changes in new production and remineralization of organic matter along the flow path. As we continue to process the physical and biogeochemical results from these cruises, we should be able to determine the large-scale changes in the carbon content of the Atlantic Ocean.

Future Directions:

The observational efforts to detect changes in water column inventories and to attribute the causes, and the development of basin wide CO_2 transport fluxes are part of well documented and justified integrated carbon plans. The CLIVAR/CO_2 Repeat Hydrography Program has a series of cruises planned for the next decade that will yield sequential basin wide inventory changes for the Atlantic, Pacific, Southern and Indian oceans. The cruise sequence is shown in the above figure at the top of the poster. NOAA/COSP has the lead on the cruises for A16S, A16N, P16N, P18 and I8. The NOAA CO_2 Science Team will begin the synthesis of these data sets beginning this fall. We will coordinate the cruise plans and logistics through the International Ocean Carbon Coordination Project

http://ushydro.ucsd.edu/ http://www.pmel.noaa.gov/co2/ http://www.aoml.noaa.gov/ocd/oaces/co2/